Fabrication and Characterization of a Micromachined In-Plane Directional Piezoelectronic Microphone

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Abstract:

The fabrication of a microelectromechanical system (MEMS) microphone, which consists of a beam that responds to a pressure gradient across its longer axis and employs piezo-electronic readout, is described. The advantages of this design included its small form factor, directionality, potentially low self-noise, and the ability to apply active feedback to the system for feedback-altered dynamics. The beam was 2.5 mm × 1.54 mm × 20 μm and fabricated out of silicon (Si). The piezoelectric material used was lead zirconate titanate (PZT). The device's directional response is presented, along with modifications for optimizing the fabrication process.

Introduction:

The purpose of this project was to develop and demonstrate a fabrication process for an in-plane directional microphone that would improve noise performance and source localization in hearing aid and advanced cell phone applications [1]. The microphone was based on a previous design inspired by the parasitoid fly *Ormia ochracea* [2], but replaced the complex optical readout with more elegant piezoelectric readout and modified the pivot mechanism to increase the sensitivity of the microphone.

The microphone consisted of a beam suspended from compliant springs. The beam exhibited high bending stiffness and low rotational stiffness, allowing it to respond to sound traveling along its longer axis (x-axis) by rotating about its shorter axis (y-axis), while preventing it from responding to sound coming in from the top (z-axis) or y-axis by bending. The rocking motion deformed the springs and strained the piezoelectronic material deposited on them, producing a voltage which could be read out (see Figure 1).

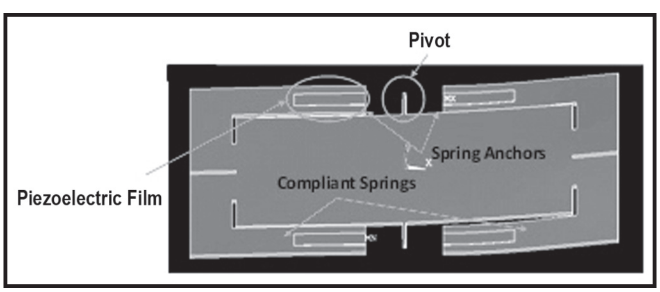

Figure 1: Operational schematic of in-plane directional microphone.

Experimental Procedure:

The device was fabricated on a silicon-with-imbedded-oxide-layer (SOI) wafer. One micrometer (μm) of low-temperature silicon oxide (SiO_x) was deposited on the top as an adhesion layer and 4 μm on the bottom as an etch mask. Titanium (Ti) was evaporated on top using electron-beam evaporation and oxidized in a 700°C furnace to form a 180 nm titanium oxide (TiO_2) diffusion barrier against the PZT.

Top and bottom electrodes for the PZT and electrode bondpads were created by using photolithography to mask the wafer, sputtering 40 nm of Ti for adhesion and 160 nm of platinum (Pt), then lifting off the excess. An 800 nm layer of commercially prepared PZT were deposited using the sol-gel method, patterned with photoresist, and wet-etched in a 200:20:2 mL solution of deionized water : hydrochloric acid : hydrofluoric acid (H_2O:HCl:HF).

The beams and springs were formed by patterning with photoresist and dry-etching through the TiO_2, SiO_x, and epitaxial Si of the SOI wafer with sulfur hexafluoride (SF_6), fluoroform (CHF_3), and SF_6 plasmas respectively. The hinges were formed by depositing 1 μm of sacrificial oxide via plasma-enhanced chemical vapor deposition (PECVD), patterning with photoresist, and dry-etching with CHF_3, then depositing 2 μm of amorphous silicon (a-Si) via PECVD, patterning with photoresist, and dry-etching with SF_6.

A deep silicon etch (DSE) was performed on the backside of the SOI wafer to remove the Si handle layer underneath the beam and springs. A cross-section of the finished device is shown in Figure 2.

Results and Future Work:

Figure 3 shows a scanning electron microscope (SEM) image of the finished device. Some problems with the fabrication process for the top electrode bondpads and hinges were discovered.

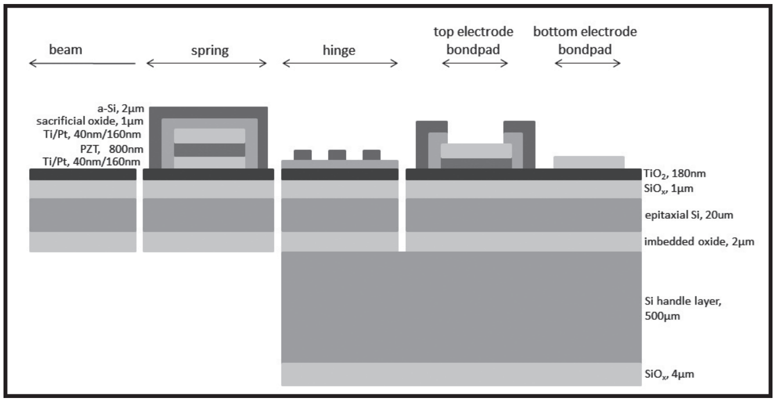

Figure 2: Cross-sectional diagram of finished device.

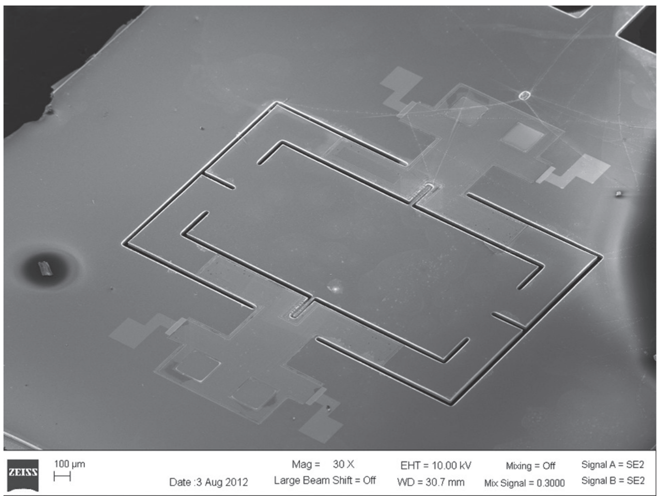

Figure 3: SEM image of finished device.

The a-Si adhered poorly to the top bondpads and peeled off, especially around the corners. In the subsequent plasma etches, the bondpads were etched through. We attribute the missing top electrode bondpads to two factors: 1) stress from depositing two different materials on top of each other, which caused the silicon to peel off most of the bondpads, leaving them exposed during the SF_6 etch, and 2) insufficient selectivity between the silicon/oxide layers and platinum during dry-etching.

To improve adhesion, we propose depositing a thinner, lower-stress Si layer and/or using circular bondpads instead of square ones to prevent the peeling that occurred around the corners, where the stress was highest. Additionally, depositing a thick layer of chrome over the platinum should reduce selectivity requirements and prevent etching through the bondpads.

The hinges designed to allow the beam to rotate freely did not turn out because the deposited a-Si had bad step coverage. This created discontinuous hinges that would not hold the pins in place if the oxide was etched from underneath. In the future, a silicon deposition method with better step coverage, such as low pressure chemical vapor deposition (LPCVD) poly-silicon, should be used to form the hinge.

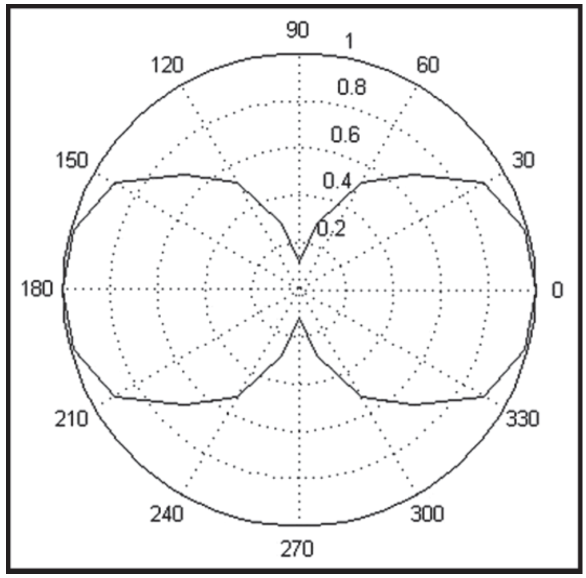

Figure 4: Directivity measurement showing the normalized sensitivity versus angle of incident sound.

In skipping the hinge release step, the hinge became a torsional pivot, allowing the beam to twist about its shorter axis, but preventing it from rotating freely.

Acoustic measurements were performed to determine the directivity of a microphone with a torsional pivot. The microphone was isolated with its x-axis facing a speaker placed 2.5′ away (0° position). The microphone was rotated in 15° increments from 0° to 90° and its sensitivity to acoustic actuation was recorded. The directivity at 11.9 kHz is displayed in Figure 4. The microphone exhibited maximum sensitivity of 14.8 mV/Pa at 0°, and minimum sensitivity of 1.70 mV/Pa at 90°, showing the expected bidirectional polar pattern with 18.8dB difference in sensitivity between the 0° and 90° positions.

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References:

[1] Amlani, A; "Speech-Clarity Judgments of Hearing-Aid-Processed Speech in Noise: Differing Polar Patterns and Acoustic Environments"; International Journal of Audiology, 45, 319-330 (2006).

[2] Miles, R; "A Low Noise Differential Microphone Inspired by the Ears of the Parasitoid Fly *Ormia Orchracea*"; Journal of the Acoustical Society of America,125, 2013-2026 (2009).